STRONTIUM

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Strontium occurs commonly in nature, averaging 0.04% of the Earth's crust, making it the 15th element in abundance (MacMillan and others, 1994). Only two minerals, celestite (strontium sulfate) and strontianite (strontium carbonate), however, contain strontium in sufficient quantities to make its recovery practical. Of the two, celestite occurs much more frequently in sedimentary deposits of sufficient size to make development of mining facilities attractive. Neither mineral is mined in the United States, although deposits have been identified and were mined in the past. The major use of strontium (as carbonate) is in color television picture tube faceplate glass. Other important uses are in ferrite ceramic magnets, pyrotechnics, and signals. Smaller uses include chemicals, electrolytic production of zinc, and pigments and fillers.

Chemical Products Corp. (CPC) of Cartersville, GA, was the only U.S. producer of strontium compounds from celestite. CPC produced strontium carbonate from imported Mexican ore.

Legislation and Government Programs

Government stockpiling of celestite began in 1942 to provide a secure supply for the production of strontium compounds required for defense applications during World War II. Celestite purchase specifications issued in 1960 for the National Defense Stockpile established quality requirements of greater than 95% strontium sulfate content with less than 1.5% calcium sulfate and less than 2% barium sulfate (U.S. Department of Defense, 1960).

In 1963, Congress determined that the celestite stockpile was unnecessary, and the General Services Administration began selling stockpiled material. All stockpile-grade celestite was sold by 1973. The remaining material graded less than 91% strontium sulfate and more than 4% calcium sulfate although some graded more than 10% barium sulfate (Defense Logistics Agency, 1998, p. 30).

In 2003, the stockpile contained approximately 12,000 metric tons (t) of celestite, all of which was authorized by Congress for disposal. No bids were made on the material that was offered for sale. Celestite has been offered for sale from the stockpile every year since 1994; none has been purchased. The low quality of the material remaining in the stockpile makes it undesirable as raw material for strontium carbonate production. Reports issued by the Defense National Stockpile Center of the Defense Logistics Agency, the agency now responsible for managing stockpile sales, list the celestite as valueless.

The U.S. International Trade Commission (ITC) investigated a petition alleging importation of color televisions at less than fair value into the United States from companies in China and Malaysia. In its preliminary determination, the ITC found reasonable indications that a U.S. industry was materially injured by these imports (U.S. International Trade Commission, 2003). In a separate preliminary investigation, the U.S. Department of Commerce (DOC) found that Chinese producers/exporters sold televisions in the United States at less than fair value, with margins between 27.94% and 45.87% below fair value. The DOC found that no harm resulted to the industry from Malaysian television imports. The DOC was expected to make its final determination for imposition of antidumping duties in 2004 (U.S. Department of Commerce, 2003§[1]).

Production

CPC voluntarily provided domestic production and sales data to the U.S. Geological Survey (USGS). Production and stock data, however, have been withheld from publication to avoid disclosing company proprietary data (table 1). CPC was the only domestic company that produced strontium carbonate from celestite; the company also produced strontium nitrate. All of the celestite that CPC used in 2003 at its Cartersville plant was imported from Mexico; CPC owned and operated a second strontium carbonate plant in Reynosa, Mexico. The company used the black ash method of strontium carbonate production at both of its facilities.

The black ash and soda ash methods are the two most common recovery techniques. The black ash method, known alternatively as the calcining method, produces chemical-grade strontium carbonate, which contains at least 98% strontium carbonate. The soda ash or direct conversion method produces technical-grade strontium carbonate, which contains at least 97% strontium carbonate.

The first step in the black ash process involves mixing the crushed and screened celestite with powdered coal. The mixture is then heated to about 1,100º C, expelling oxygen in the form of carbon dioxide from the insoluble strontium sulfate to form water-soluble strontium sulfide. Strontium sulfide is dissolved in water, and the resulting solution is filtered. Then, either carbon dioxide is passed through the solution or soda ash is added, forming and precipitating strontium carbonate from the solution. The precipitated strontium carbonate is filtered, dried, ground, and packaged. The byproduct sulfur from the process is recovered as elemental sulfur or other byproduct sulfur compounds (Mannsville Chemical Products Corp., 1993). The black ash method is the preferred method of strontium carbonate production because it yields a higher grade product; most new production facilities employ black ash technology.

In the soda ash method, ground celestite is washed, and most of the water is removed. The thickened mixture is combined with soda ash and treated with steam for 1 to 3 hours. During

[1]References that include a section mark (§) are found in the Internet References Cited section.

this time, celestite and soda ash react to form strontium carbonate and sodium sulfate. Sodium sulfate is water soluble, making it possible to separate the insoluble strontium carbonate by centrifuging.

Several U.S. companies produced strontium compounds from strontium carbonate. Mallinkrodt Chemical Inc. of St. Louis, MO, and Laporte Pigments Corp. of Beltsville, MD, produced strontium chloride and strontium chromate, respectively. A few other companies produced downstream strontium compounds on a limited scale.

Consumption

The USGS estimated the distribution of strontium compounds by end use. Of the six operations to which a survey request was sent, five responded. The information collected from this survey and the information provided by the U.S. Census Bureau on strontium trade were the bases for the end-use estimates listed in table 2.

In 2003, almost 85% of all strontium was consumed in ceramics and glass manufacture, primarily in television faceplate glass and secondarily in ceramic ferrite magnets and other ceramic and glass applications. Since 1970, production of faceplate glass for color television picture tubes has been the major use of strontium.

All color televisions and other devices that contain color cathode-ray tubes (CRTs) sold in the United States are required by law to contain strontium in the faceplate glass of the picture tube to block x-ray emissions. Major manufacturers of television picture tube glass incorporate, by weight, about 8% strontium oxide in their glass faceplate material. Added to the glass melt in the form of strontium carbonate, strontium is converted to strontium oxide. In addition to blocking x rays, strontium improves the appearance of the glass and the quality of the picture and increases the brilliance (Wagner, 1986).

Permanent ceramic magnets were another large end use for strontium compounds in the form of strontium ferrite. These magnets are used extensively in small direct-current motors for automobile windshield wipers, loudspeakers, magnetically attached decorative items, toys, and other electronic equipment. Strontium ferrite magnets have high coercive force and high thermal and electrical resistivities and are chemically inert. They retain their magnetism well, are not adversely affected by electrical currents or high temperatures, do not react with most chemical solvents, and have a low density (Haberberger, 1971).

One of the most consistent and continuing applications for strontium is in pyrotechnic devices. Strontium burns with a brilliant red flame, and no other material is known to perform better in this application. The compound used most frequently in these devices is strontium nitrate. Although strontium carbonate, strontium chlorate, strontium oxalate, and strontium sulfate could also be used, strontium nitrate was used in significantly larger quantities. Pyrotechnic devices are used in military and nonmilitary applications. Military pyrotechnic applications include marine distress signals, military flares, and tracer ammunition. Nonmilitary applications include fireworks and warning devices (Conkling, 1981).

Strontium can be used to remove lead impurities during the electrolytic production of zinc. The addition of strontium carbonate dissolved in sulfuric acid reduces the lead content of the electrolyte and of the zinc deposited on the cathode (Bratt and Smith, 1963).

Strontium chromate is used as an additive to corrosion-resistant paint to effectively coat aluminum, most notably on aircraft fuselages and ships. These paints are used, to some degree, on aluminum packaging to prevent corrosion (Roskill Information Services Ltd., 1992, p. 76).

Strontium metal was a very small part of total strontium consumption. Small amounts of strontium added to molten aluminum improved the castability of the metal, making it more suitable for casting items that have been made traditionally from steel, such as engine blocks and wheels. The addition of strontium to the melt also improves the machinability of the casting. The use of cast aluminum parts has become common in the automotive industry because of the reduced weight and improved gas mileage achieved from the use of cast aluminum parts instead of steel (Lidman, 1984).

Other end uses consumed only small amounts of strontium and strontium compounds. As mentioned above, the presence of strontium in glass applications improves the brilliance of the glass. It also improves the quality of certain ceramic glazes and eliminates the toxicity that may be present in glazes that contain barium or lead. Strontium titanate is sometimes used as a substrate material for semiconductors and in some optical and piezoelectric applications. Strontium chloride is used in toothpaste for temperature-sensitive teeth. For this application, impurities must be strictly controlled; some limits are in the parts-per-million range. Strontium phosphate is used in the manufacture of fluorescent lights, and the entire range of strontium chemicals is used in analytical chemistry laboratories.

Prices

Based on data published by the U.S. Census Bureau, the average customs value for celestite imported from Mexico was about $58 per metric ton, 3% lower than that of 2002. The average unit customs value of imported strontium carbonate was $0.48 per kilogram, a decrease of 13% from $0.55 in 2002. In 2003, the corresponding value for strontium nitrate was $2.95 per kilogram, an 11% increase from $2.66 per kilogram in 2002.

Foreign Trade

Exports of strontium compounds were nearly double those of 2002 but were still significantly lower than the quantity reported prior to 2002 (tables 1, 3). Imports of celestite from Mexico were 2,320 t, a decrease of 10% from the previous year and a 93% decrease from the level reached in 1999, a tremendous decrease during this 5-year period.

Mexico continued to be the most important source for imported strontium compounds with 92% of the total, followed by Germany with 5% (table 4). Imports of strontium carbonate in 2003 were 9% lower than those of 2002. Imports from Mexico were 94% of total strontium carbonate imports. Imports of strontium nitrate, the second leading imported strontium compound, vary significantly from year to year but typically represent less than 2% of total strontium imports. In 2003, imports of strontium nitrate were 9% lower than those of 2002.

World Industry

In most instances, celestite deposits occur in remote, undeveloped locations far from population centers and in areas where inexpensive labor is available for mining. Huge deposits of high-grade celestite have been discovered throughout the world. Strontium commonly occurs along with barium and calcium, two elements with chemical properties very similar to strontium, thus making separation difficult. Because removing many impurities from celestite is difficult and energy-intensive, strontium chemical producers require that raw materials contain at least 90% strontium sulfate. Most operating celestite facilities can produce sufficient supplies with only minimal processing necessary to achieve acceptable specifications. Hand sorting and some washing are all that are necessary at many strontium mines; a few operations use froth flotation, gravity separation, or other methods to beneficiate ore.

The leading celestite producing countries were, in decreasing order of importance, Spain, Mexico, and Turkey. Significant quantities of celestite were produced in China and Tajikistan; however, not enough information was available to make any estimates on the location, number, or size of mines. Celestite was produced in smaller quantities in Argentina, Iran, Morocco, and Pakistan (table 5). Production facilities for strontium compounds and metal were located in Canada, China, Germany, Japan, the Republic of Korea, Mexico, and the United States.

Detailed information on most world resources was not readily available because very little information on exploration results has been published. Other deposits may be well identified but are in countries from which specific minerals information was not easily obtained.

World Review

Canada.—The world's leading producer of strontium metal, Timminco Ltd., produced strontium metal in Ontario. The company also produced strontium-aluminum master alloys, which were advertised as the highest quality in the world, referring to their purity, low gas content, fast dissolution rate, low porosity, and precise weight. Timminco sold strontium as crowns, sections, and turnings and in master alloys that contained 90% strontium and 10% aluminum (Timminco Ltd., 2004§).

China.—A long-time producer of celestite and strontium carbonate, China's strontium carbonate capacity has expanded dramatically, making it the leading producer in the world with more than 200,000 metric tons per year (t/yr) in 2003 compared with about 50,000 t/yr in 1995. Although production data are not available, celestite production was thought to be insufficient to meet domestic demand, so China has become a major importer of celestite to supply its strontium carbonate plants. Strontium carbonate is used to produce televisions and magnets in China, but the majority of it is exported. Exports grew to 97,000 t in 2002 from 42,000 t in 1995 (Coope, 2003).

Although China may have sufficient reserves to supply its domestic strontium carbonate plants, celestite concentrates range from 80% to 85% strontium-sulfate content, much lower quality than products from deposits in Mexico, Spain, and Turkey. Celestite is produced from the Hechuan deposit in Sichuan Province and from the Lishui deposit in Jiangsu Province. Reserves were reported to be nearly 30 million metric tons (Mt) (Coope, 2003). Celestite is also produced in Henan Province (Harben and Kužvart, 1996; Coope, 2003). A strontium carbonate plant in Sichuan Province was the only one in the world that produced strontium from strontianite. Technical problems hampered the success of the process, and the current status of the plant is unknown (Hong, 1993).

Germany.—Solvay Barium Strontium GmbH (a subsidiary of Belgium's Solvay S.A.) operated a 150,000-t/yr barium and strontium carbonate plant at Bad Honningen. Solvay used imported Spanish celestite as the raw material for strontium carbonate production in Germany. Including its strontium carbonate plants in Italy, the Republic of Korea, and Mexico, Solvay S.A. is the world's leading strontium carbonate supplier (Solvay S.A., 2002§).

Malawi.—Rift Valley Resource Development Ltd. was conducting a feasibility study on the development of the Kangankunde strontianite/rare-earths deposit. The Malawian Geological Survey reported that the deposit contained 11 Mt of strontianite and monazite (a rare-earth mineral). Phase 1 of development would produce strontium carbonate for export and monazite concentrates that would be stockpiled for later phases of the project. Strontium carbonate production was expected to be about 20,000 t/yr (Tassell, 2002). The European Investment Bank and the Development Bank of South Africa were funding the feasibility study (Saner, 2002).

Mexico.—Mexico was the world's second leading celestite producer in 2003 with three strontium carbonate plants operated by CPC, Cia. Minera La Valenciana S.A. de C.V. (CMV), and Solvay Química y Minera, S.A. de C.V. Mexico also was the world's second leading strontium carbonate producing country. The majority of all strontium imports, including minerals and compounds, into the United States came from Mexico. The leading Mexican celestite producer is Minas de Celestita S.A. de C.V., a company completely controlled by CPC. Minas de Celestita controls celestite reserves of between 6 and 6.5 Mt of proven and inferred ore that is mined to supply its operations in Mexico and the United States. CPC operates a 50,000-t/yr strontium carbonate plant in Reynosa, Tamaulipas State (Moore, 2002).

CMV reported proven and estimated reserves of 5 Mt, enough to continue production well into the future (Cia. Minera La Valenciana S.A. de C.V., undated§). Other sources suggested that CMV's San Augustin Mine near Torreon was nearing depletion after lifetime production of more than 1 Mt.

Solvay operated a 27,000-t/yr strontium carbonate plant near Monterrey using celestite mined by Minera La Roja, S.A. de C.V. (Moore, 2002).

Spain.—As a result of increased exports to China, Spain became the world's leading celestite producer in 2003. Celestite was mined at two locations. The Montevive deposit, which is mined by Canteras Industriales S.L., has been in production since about 1940, and the Escuzar deposit, which is mined by Solvay Minerales S.A. (a subsidiary of Solvay), has been in production since 1989 (Griffiths, 1992; Coope, 1997). The Montevive deposit contained 8 Mt of estimated reserves grading 80% strontium sulfate. Selective mining, hand sorting, crushing, and sorting by size result in a product that contains 95% of strontium sulfate. A mobile secondary screen separates a second 90% strontium sulfate product; additional concentration facilities are planned. Much of the Montevive production was exported to China. The Escuzar deposit has reserves estimated to be about 4 Mt of 54% strontium sulfate. More complicated beneficiation techniques than those used at Montevive produced a 94% strontium sulfate concentrate. Most of this material was exported to Solvay in Germany or Daehan Specialty Chemical Co. in the Republic of Korea (Regueiro, 1998).

Quimico Estroncio (a joint venture of Minas de Almadadén y Arrayanes, S.A., Fertiberia S.A., Solvay, and Erkros Industrial S.A.) built a 20,000-t/yr strontium carbonate plant in Cartegena that opened in 2000 and has been expanded to 35,000 t/yr. The plant uses an unusual technology for strontium carbonate production. It seems to have experienced some technical problems scaling up to commercial production. The plant is producing, but actual production statistics are unavailable (Coope, 2003; Regueiro y González-Barros and Marchán Sanz, 2004).

Outlook

Sales of televisions and computer monitors in the United States will continue to influence U.S. strontium consumption significantly. Increased imports of faceplate glass and imported televisions from Asia and decreased growth in CRT demand will contribute to lower domestic consumption of strontium compounds. One of the three faceplate-glass plants in the United States closed in 2003 as a result of the weakened CRT market in North America, reducing the domestic consumption of strontium carbonate in that end use (Industrial Minerals, 2003a). As long as CRTs are used in television and computer monitors, world consumption should continue but at lower growth rates than have been experienced in recent years. Ferrite-magnet markets are expected to be strong. Growth in other markets will probably continue at the current slower rate. Improved economic conditions worldwide could spur growth in demand for strontium carbonate.

Flat screen display systems for televisions and computer monitors have threatened to replace CRTs for many years, but the cost of the new technology has restricted growth. Flat panels, however, have begun to have an impact on the CRT market, and the flat panel market is growing at a much higher rate than that of the CRT market. As a result, a leading producer of CRTs closed one of its plants in the United Kingdom (Industrial Minerals, 2003b). Improvements have increased the likelihood that the large flat screens that use either liquid crystal displays (LCD) or plasma technology will replace bulkier CRTs. LCDs, which are smaller and use less energy than plasma display systems, seem to be filling the market for relatively small flat displays, such as those required for portable computers. The market for LCD materials is expected to grow at a rate of about 16% per year through 2005 (Markarian, 2002).

Worldwide, about 150 million CRTs per year are produced. Sales of plasma displays are expected to approach 4 million units by 2005, about 3% of the total market (Tremblay, 2002). Domestic sales of plasma televisions totaled $919 million in 2003 with expected growth to $2.5 billion in 2004 (Thottam, 2004). Plasma technology is more common for large, high-definition televisions with screens measuring 60 inches diagonally and wider, but larger LCDs are being developed (Tremblay, 1999; Thottam, 2004). Neither LCD nor plasma technology require strontium carbonate in the glass, but both have been too expensive to make serious inroads in the domestic CRT market until now. The price of larger plasma screens (usually between 37 and 60 inches diagonally) was between $10,000 and $14,000 in 2000 (Landers, 2000). In 2002, prices were reported to be between $6,000 and $10,000 for similar items, a significant decrease, but still quite expensive (Tremblay, 2002). Major retailers, however, were offering some 42-inch plasma display systems at $3,000 and below. The $2,999 price was considered a “breakthrough” in consumer electronics, making the devices affordable for many families (Thottam, 2004). As these new display systems become more economically attractive to consumers, CRTs will become obsolete and so will the major market for strontium carbonate.

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TABLE 1
SALIENT STRONTIUM STATISTICS[1]

(Metric tons of contained strontium and dollars per metric ton)[2]

	1999	2000	2001	2002	2003
United States:					
Production, strontium minerals	--	--	--	--	--
Imports for consumption:[3]					
Strontium compounds	26,800	29,900	26,500	25,400	23,300
Strontium minerals	13,700	7,460	5,640	1,150	1,020
Exports, compounds[3]	2,890	4,520	929 r	340	693
Shipments from Government stockpile excesses	--	--	--	--	--
Apparent consumption[4]	37,600	32,800 r	31,200	26,500	23,600
Price, average value of mineral imports at port of exportation	73	62	63	60	58
World, production of celestite[5]	358,000 r	346,000 r	348,000 r	335,000 r	367,000 e

e Estimated. r Revised. -- Zero.
[1]Data are rounded to no more than three significant digits.
[2]The strontium content of celestite is 43.88%, which was used to convert units to celestite.
[3]Source: U.S. Census Bureau.
[4]Production plus imports minus exports.
[5]Excludes China and Tajikistan, which produced significant quantities of celestite, but information was not available to make reliable estimates.

TABLE 2
U.S. ESTIMATED DISTRIBUTION OF PRIMARY STRONTIUM COMPOUNDS, BY END USE

(Percent)

End use	2002	2003
Electrolytic production of zinc	2	2
Ferrite ceramic magnets	9	10
Pigments and fillers	2	2
Pyrotechnics and signals	9	10
Television picture tubes	75	73
Other	3	3
Total	100	100

TABLE 3
U.S. EXPORTS OF STRONTIUM COMPOUNDS, BY COUNTRY[1]

	2002		2003	
	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Strontium carbonate, precipitated:				
Canada	76,500	$59,600	42,600	$39,600
Germany	15,000	125,000	32,000	130,000
Hong Kong	16,400	28,900	35,100	50,600
Japan	3,840	3,590	12,300	12,600
Korea, Republic of	--	--	171,000	62,800
Mexico	--	--	60,500	57,500
Tokelau	--	--	2,580	3,040
United Kingdom	3,370	26,500	18,600	96,300
Total	115,000	244,000	375,000	452,000
Strontium oxide, hydroxide, peroxide:				
Australia	11,600	18,200	--	--
Brazil	--	--	6,910	20,000
Canada	20,400	11,200	50,500	26,200
Germany	--	--	35,400	19,500
Korea, Republic of	63,900	35,100	--	--
Mexico	189,000	104,000	523,000	287,000
Netherlands	--	--	29,200	16,100
Norway	34,400	18,900	--	--
Sweden	57,200	31,500	--	--
Thailand	--	--	8,410	4,630
Total	377,000	219,000	653,000	374,000

-- Zero.
[1]Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Free alongside ship value.

Source: U.S. Census Bureau.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF STRONTIUM COMPOUNDS, BY COUNTRY[1]

	2002		2003	
	Gross weight (kilograms)	Value[2]	Gross weight (kilograms)	Value[2]
Celestite, Mexico	2,580,000	$154,800	2,320,000	$135,000
Strontium carbonate:				
Belgium	142,000	64,400	61,800	26,100
China	392,000	164,000	114,000	45,000
France	79,400	46,400	--	--
Germany	1,970,000	917,000	2,060,000	900,000
Italy	10,800	31,900	1,000	6,620
Japan	3,700	45,900	--	--
Mexico	39,400,000	21,900,000	35,800,000	17,200,000
Netherlands	--	--	20,600	8,170
Spain	19,400	9,480	200,000	85,300
United Kingdom	10	2,560	20	5,390
Total	42,000,000	23,200,000	38,200,000	18,200,000
Strontium metal:				
Canada	30,500	193,000	39,900	263,000
China	48,700	102,000	15,000	72,300
France	10,000	68,500	10,000	67,700
Japan	62,400	245,000	218,000	682,000
United Kingdom	4,000	5,420	300	2,570
Total	156,000	615,000	283,000	1,090,000
Strontium nitrate:				
Canada	20,000	15,400	--	--
China	399,000	321,000	375,000	261,000
France	70,000	433,000	--	--
Japan	160,000	1,190,000	252,000	1,750,000
Mexico	123,000	92,800	77,100	56,300
Singapore	--	--	12	7,250
United Kingdom	--	--	18	2,210
Total	771,000	2,050,000	705,000	2,080,000
Strontium oxide, hydroxide, peroxide:				
Australia	1,050	2,730	--	--
China	72,000	49,000	--	--
Germany	9	13,500	--	--
Japan	303	8,750	--	--
Total	73,400	74,000	--	--

-- Zero.

[1]Data rounded to no more than three significant digits; may not add to totals shown.

[2]Free alongside ship value.

Source: U.S. Census Bureau.

TABLE 5

CELESTITE: WORLD PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	1999	2000	2001	2002	2003[e]
Argentina	2,141	4,656 [r]	2,440 [r]	3,106 [r]	3,323 [p]
Iran[e, 4]	1,650 [5]	2,000	2,000	2,000	2,000
Mexico	164,682	157,420	145,789	94,015 [r]	126,747 [p]
Morocco	--	7,539 [r]	1,879 [r]	3,780 [r]	2,700
Pakistan	634	1,918	2,000 [e]	2,000 [e]	2,000
Spain	128,457 [r]	148,352 [r]	129,794 [r]	160,519 [r]	160,000
Turkey	60,540 [r]	24,150 [r]	63,635 [r]	70,000 [e]	70,000
Total	358,000 [r]	346,000 [r]	348,000 [r]	335,000 [r]	367,000

[e]Estimated. [p]Preliminary. [r]Revised. -- Zero.

[1]World totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[2]Table includes data available through May 20, 2004.

[3]In addition to the countries listed, China and Tajikistan produce strontium materials, but output is not reported quantitatively, and available information is inadequate to make reliable estimates of output levels.

[4]Data are for year beginning March 21 of that stated.

[5]Reported figure.